Flux tube emergence from the convection zone to the corona: HINODE observations and 3D simulations

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2nd Hinode Science Meeting, 30-Sept 2008

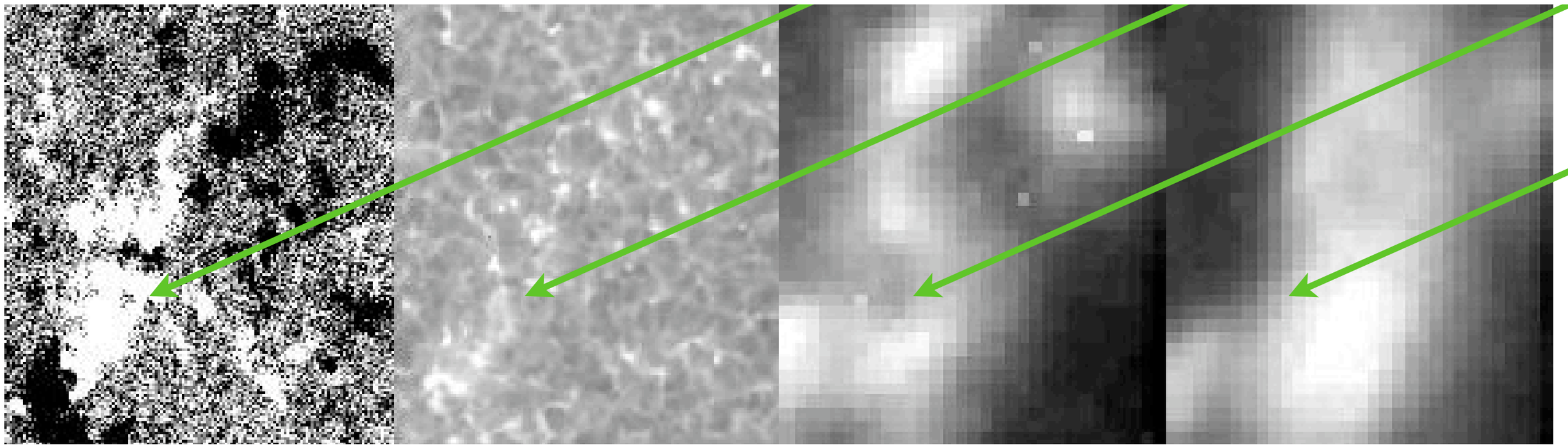
Paper in Apj and work in preparation

Chromosphere: Observational evidence from Hinode

Flux emergence

Granule expansion

Cold Bubble in the Chromosphere



Fe I magnetogram

Ca II image

He II image

Fe XII image

References: V. Hansteen et al PASJ 2007

Observational findings

- Flux emergence.
- Enlarged granulation in photosphere
- Large dark granules in Ca II
- Bright points in the boundary of large granules
- Darkening in Transition Region (He II)
- ... and Corona (Fe XII)
- Whole process takes the order of one hour.

The MHD equations: OSC

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\frac{\partial e}{\partial t} + \nabla \cdot (e\mathbf{u}) + p\nabla \cdot \mathbf{u} = \nabla \cdot \mathbf{F}_r + \nabla \cdot \mathbf{F}_c + \eta j^2 + Q_{visc}$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{u} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$$

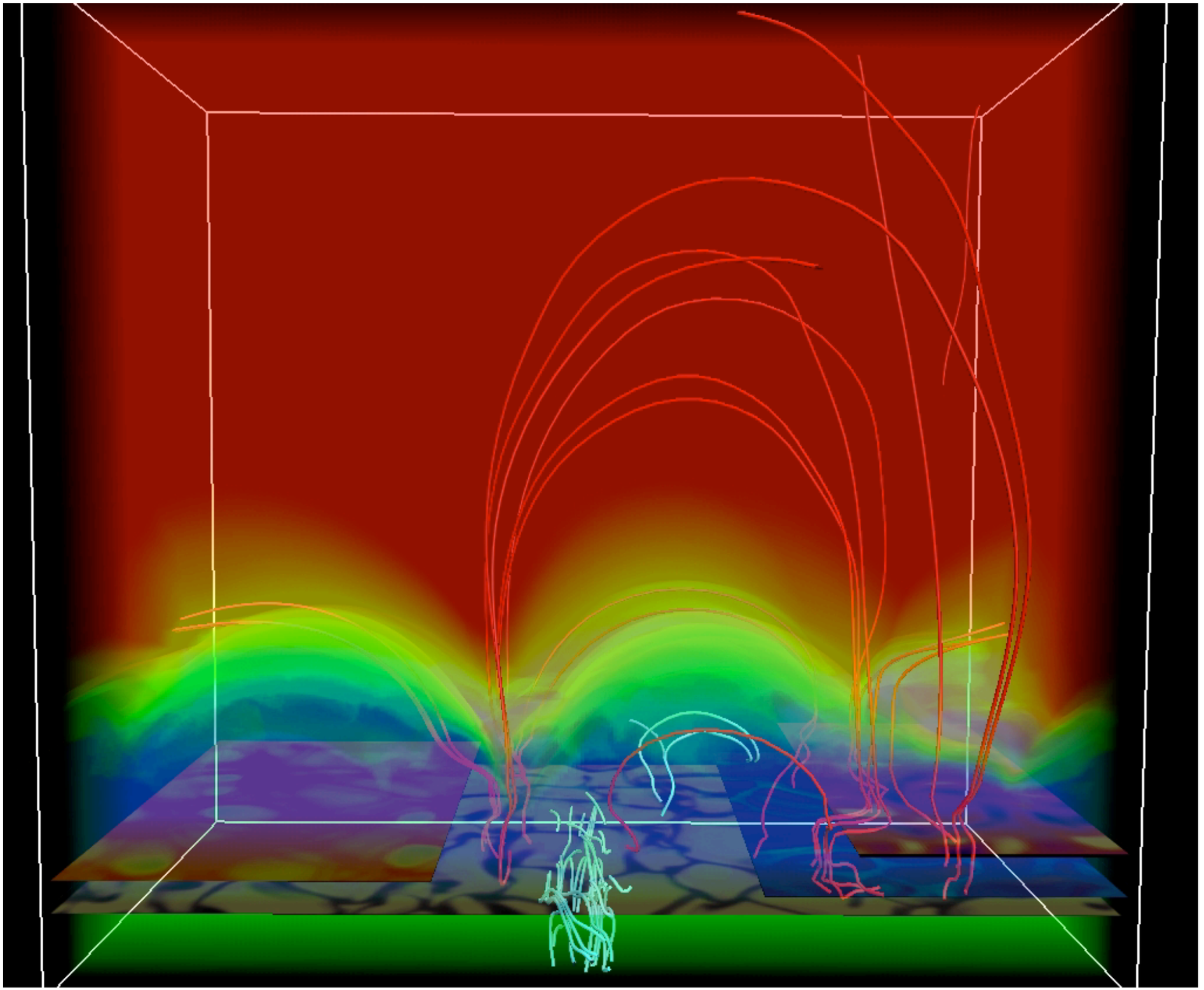
$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u} + \tau) = -\nabla p + \mathbf{j} \times \mathbf{B} - g\rho$$

Equation of state:

Tables based on the Uppsala Opacity Package

T, P , opacity (χ_i), destruction probability (ε_i), and bin average of the Plank function (B_i) in each opacity bin i as functions of (e/ρ) and density.

Initial Setup



256x128x160 points
32 km dx,dy
32 km dz except in corona
16x8x16 Mm

Corona

Transition region

Chromosphere

Photosphere

Injection of field at the bottom boundary

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

set electric field at boundary to strive for desired field:

$$E_x^n = E_x - \frac{\Delta(B_y)}{\tau}\Delta z \qquad \Delta(B_y) = B_y^n - B_y$$

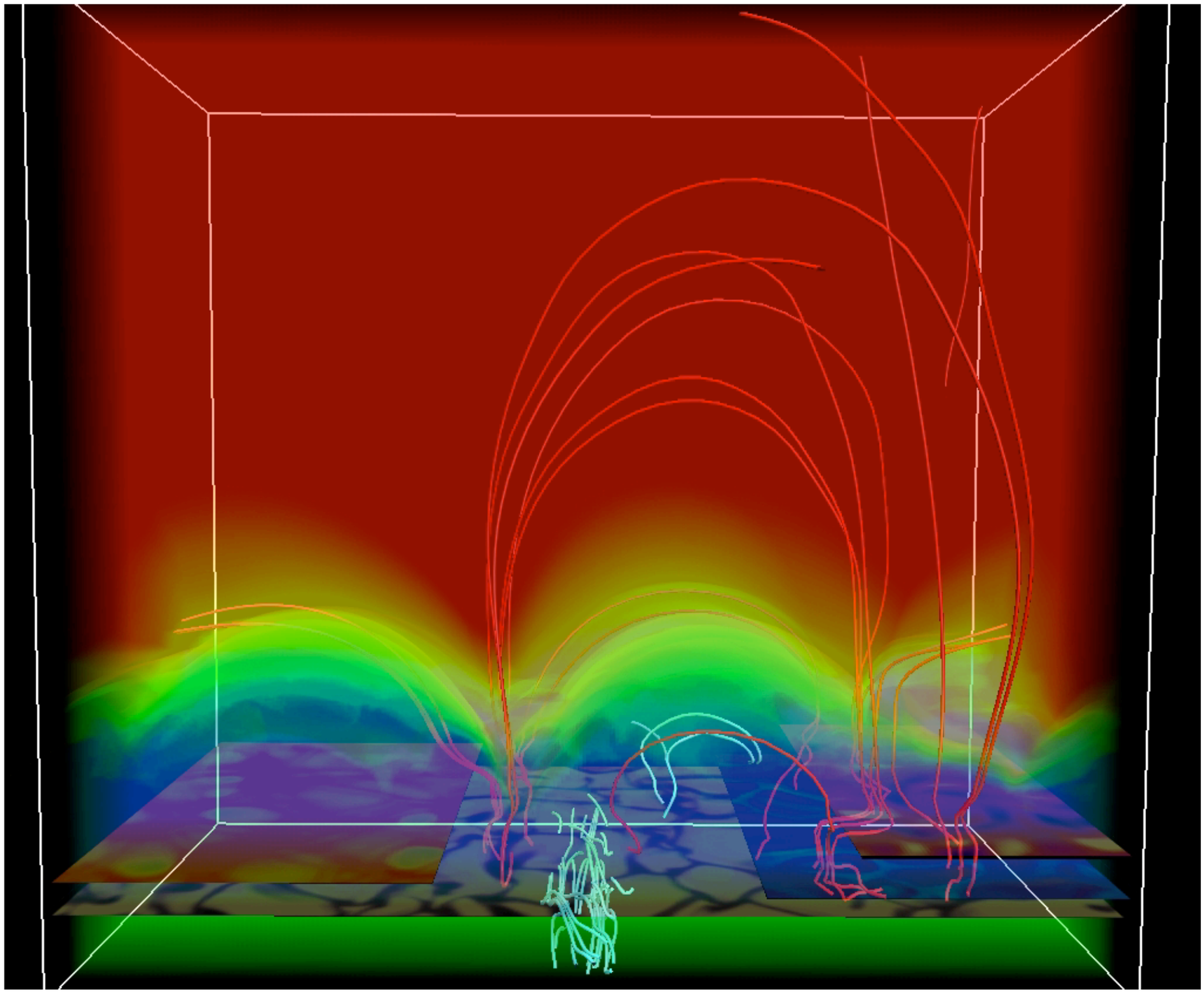
For example flux tube with twist

$$\mathbf{B}_{long} = B_o \exp\left(-\frac{r^2}{R^2}\right) \mathbf{e}_z$$

$$\mathbf{B}_{trans} = B_{long}\, r\, q\, \mathbf{e}_\phi,$$

$$r = \sqrt{(x - x_o)^2 + (z - z_o)^2} \qquad \lambda = q\, R.$$

Initial Setup: Evolution



256x128x160 points
32 km dx,dy
32 km dz except in corona

Corona

Transition region

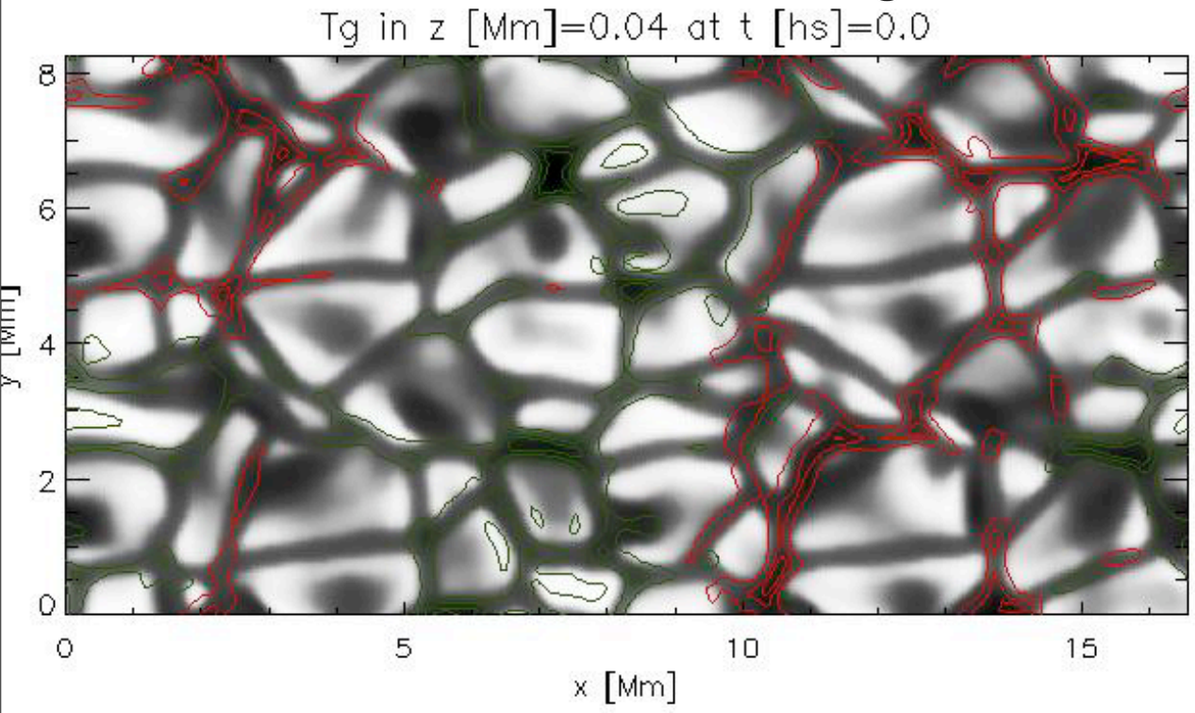
Chromosphere

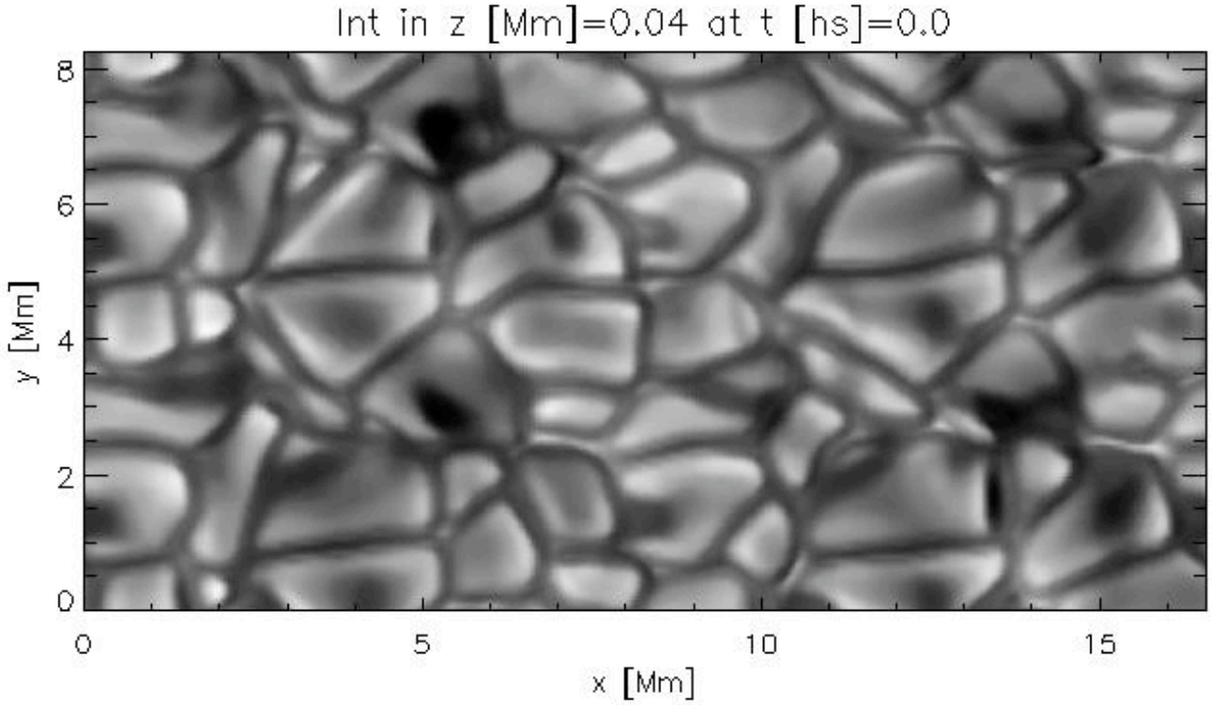
Photosphere

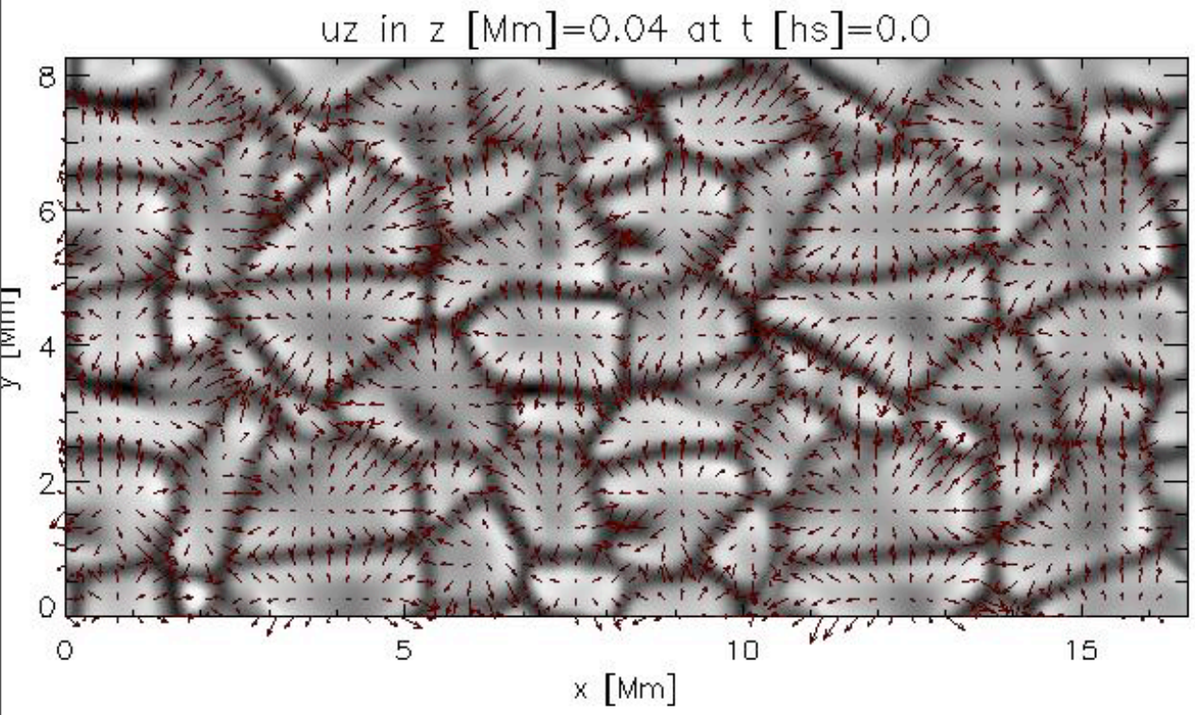
Granulation pattern in photosphere:

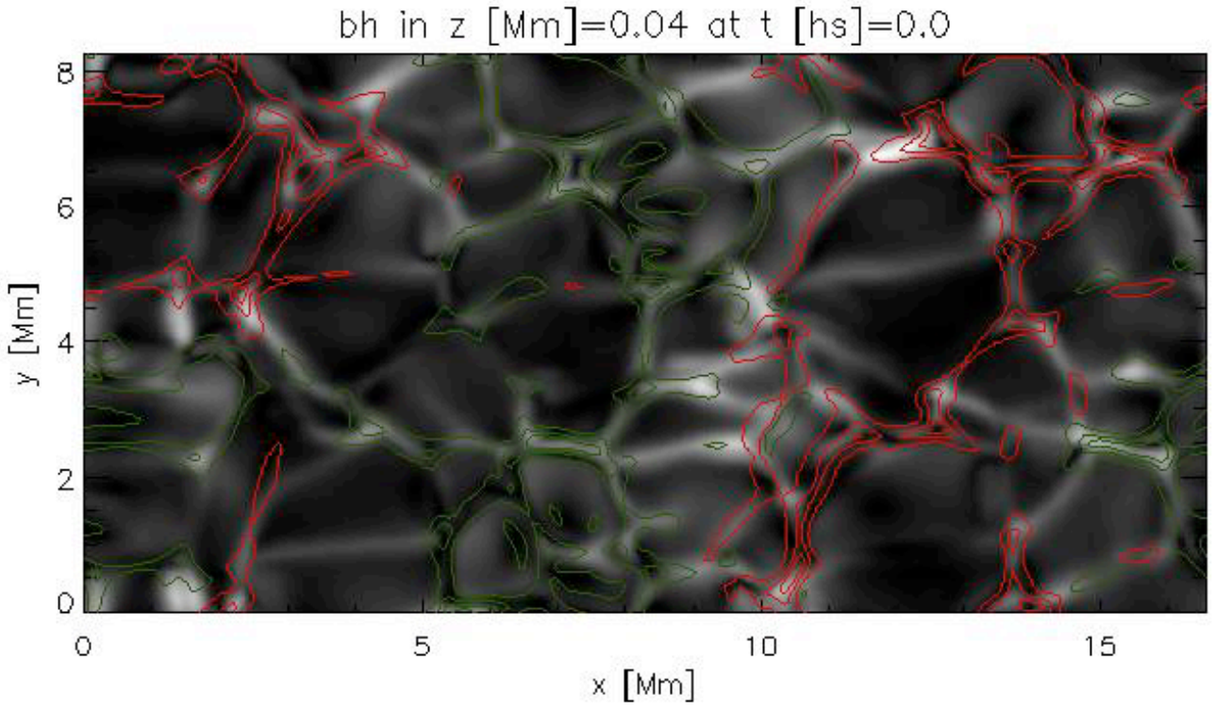
Expansion, collapsed and bright points.

Agree with M. Cheung et al. 2007





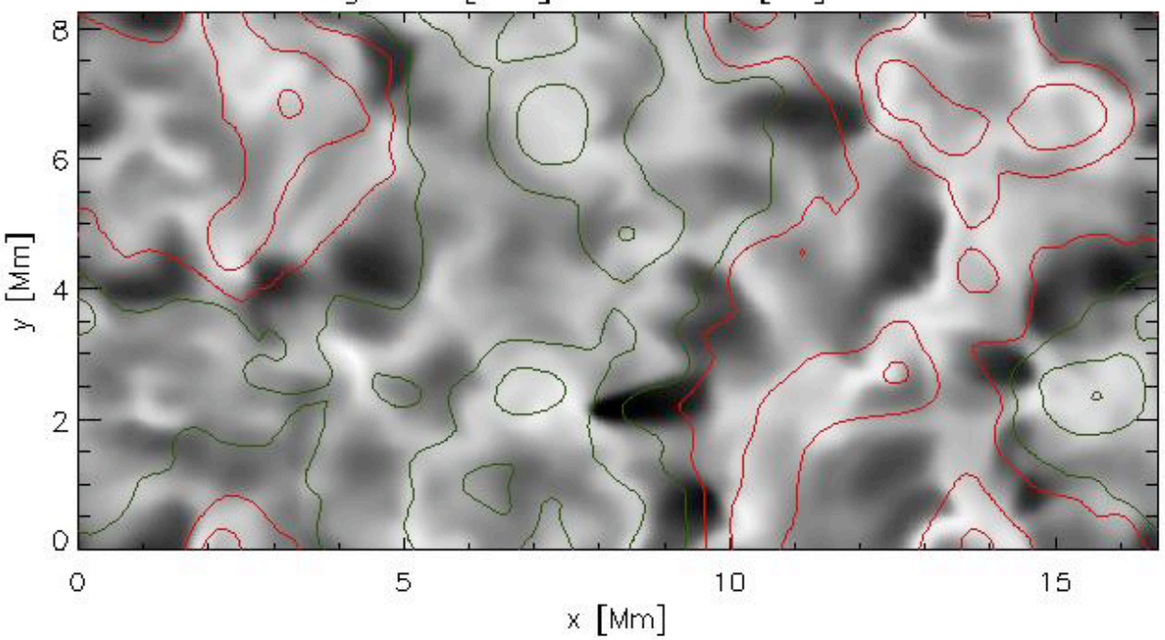


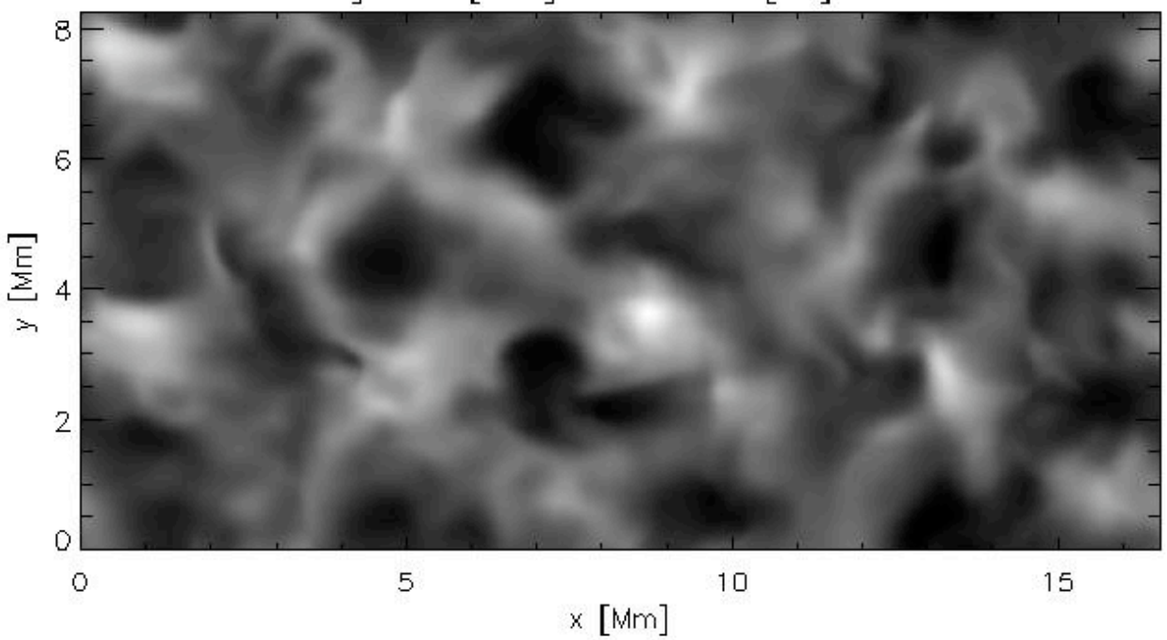


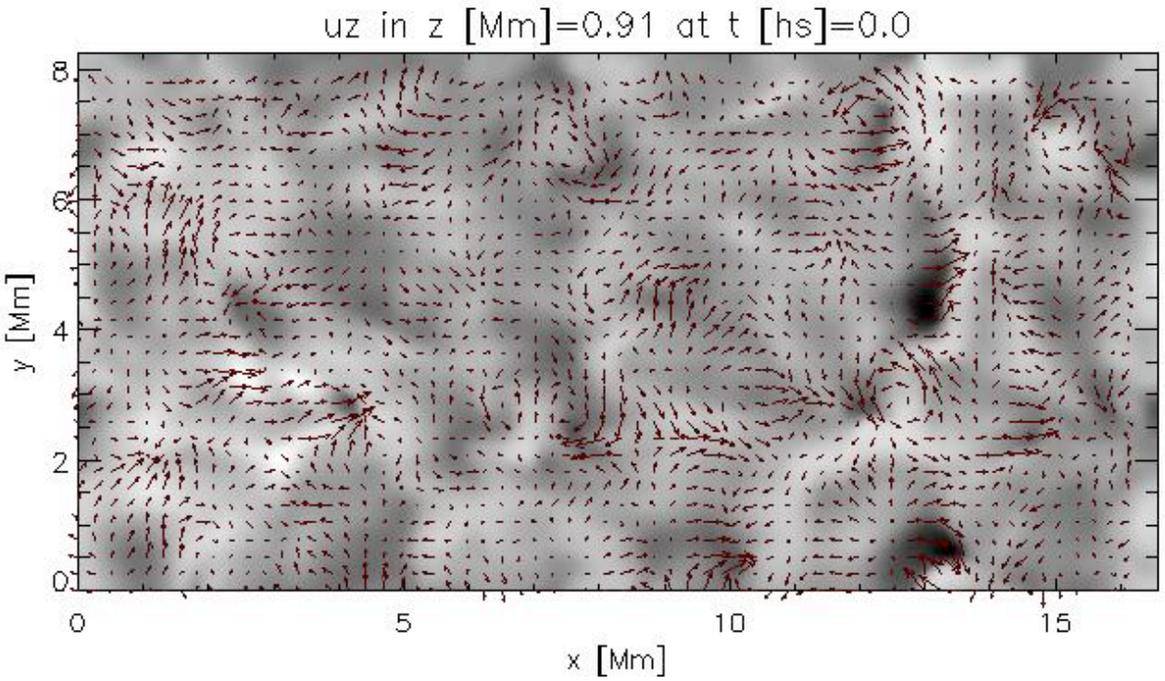
Chromosphere:

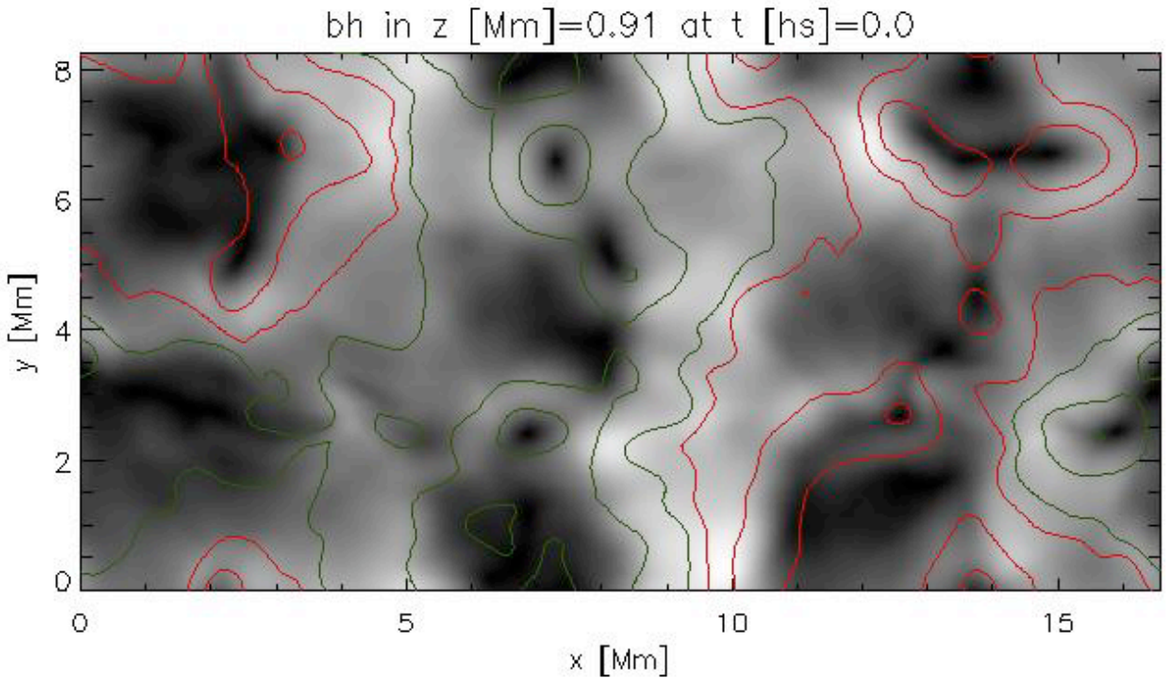
Shock dominated - Magnetic dominated

(900km)

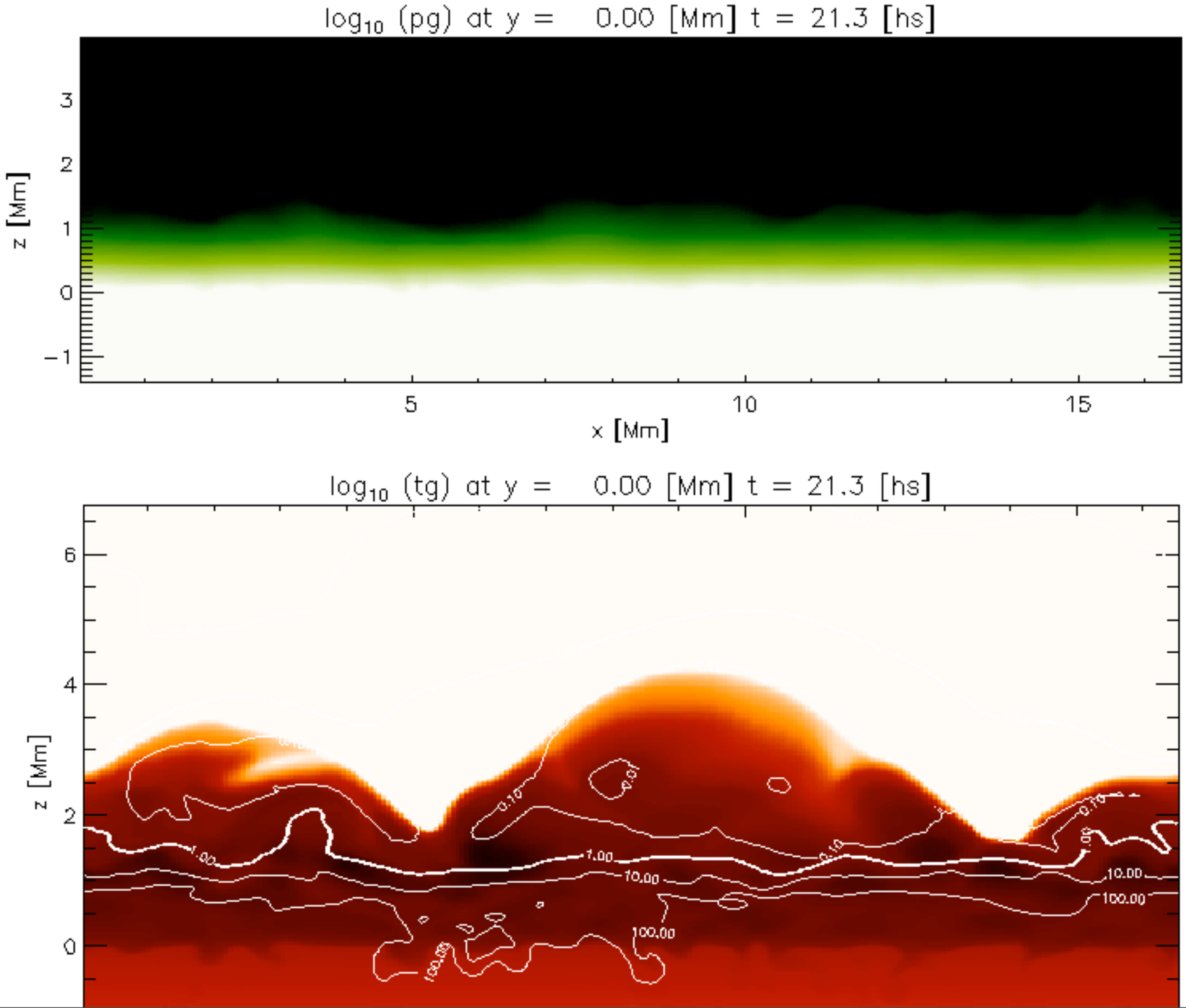






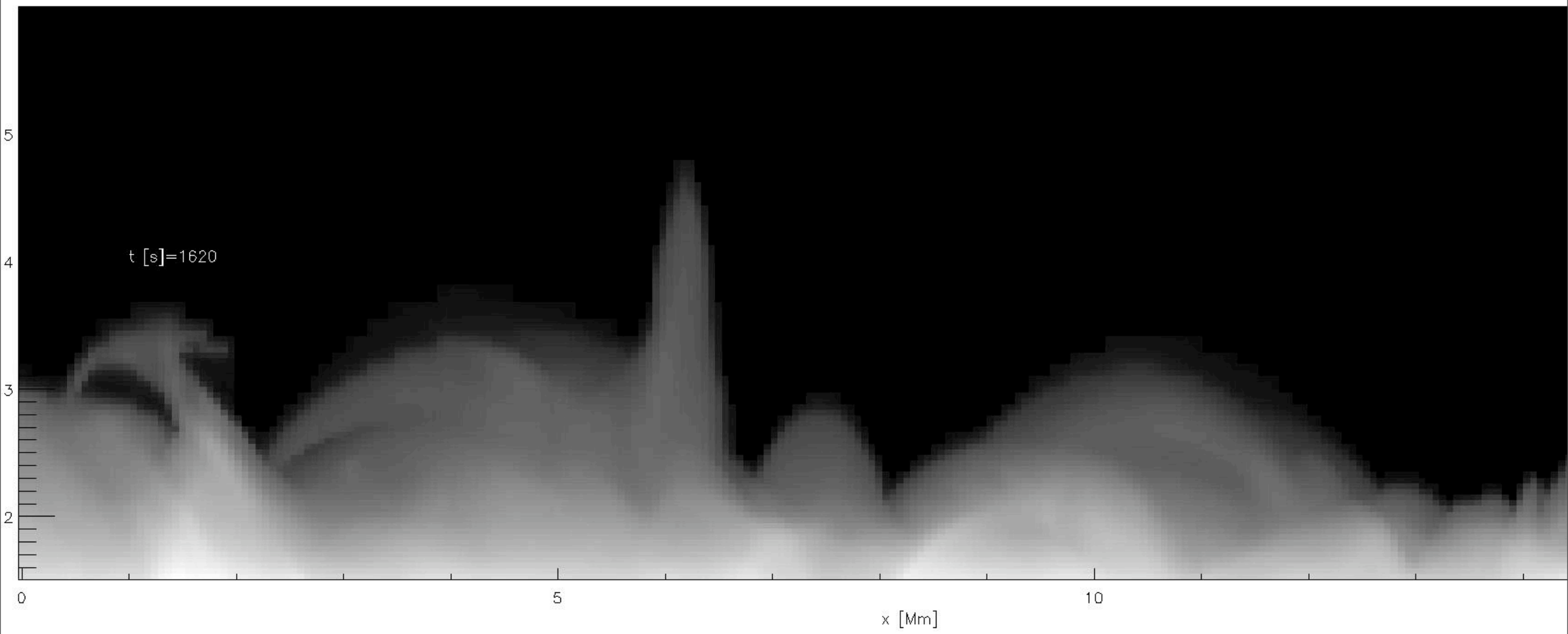


Chromosphere: Cool regions and expansion of the Transition Region



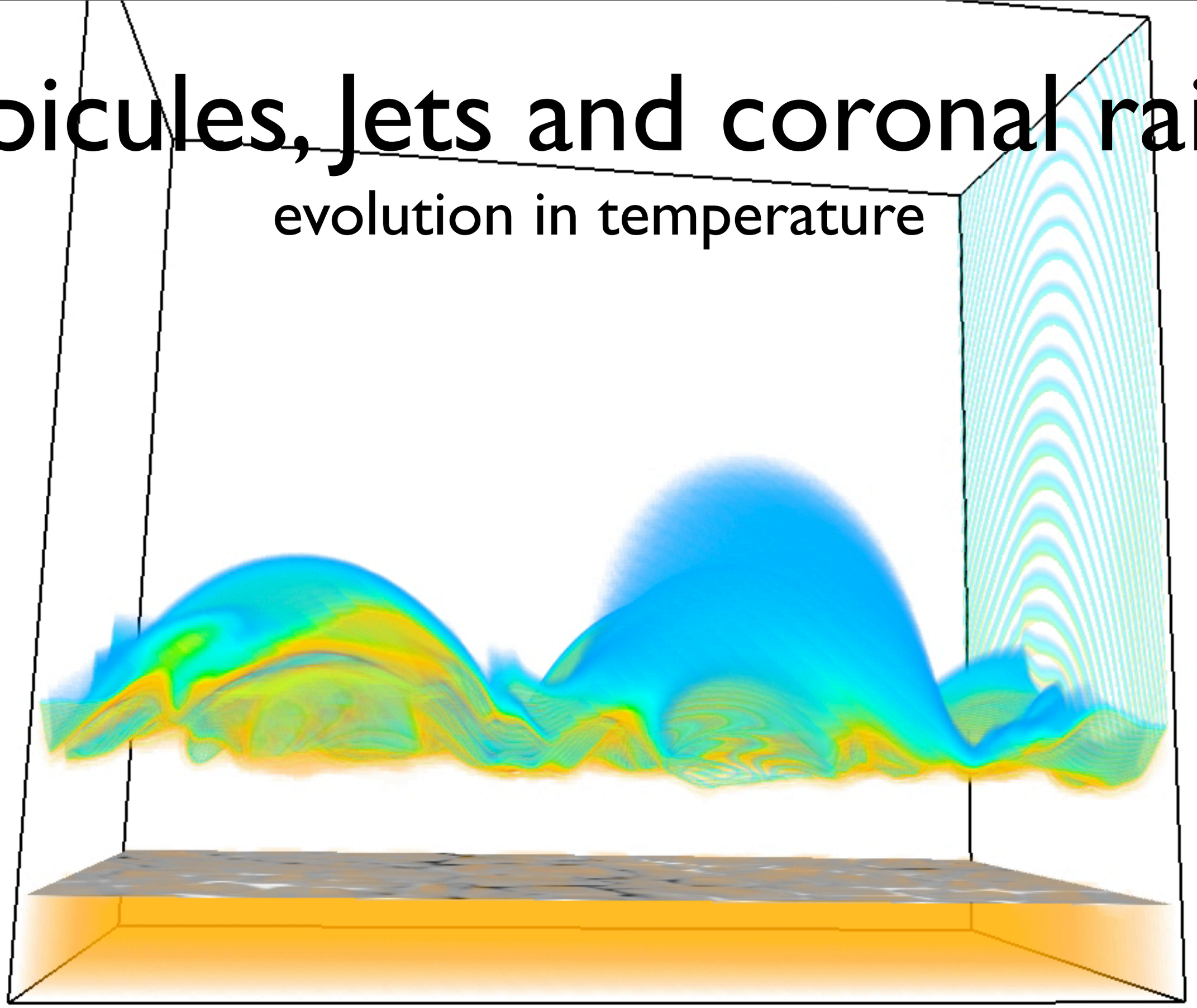
Ca II from the limb:

Spicules, Jets and rain



Spicules, Jets and coronal rain

evolution in temperature

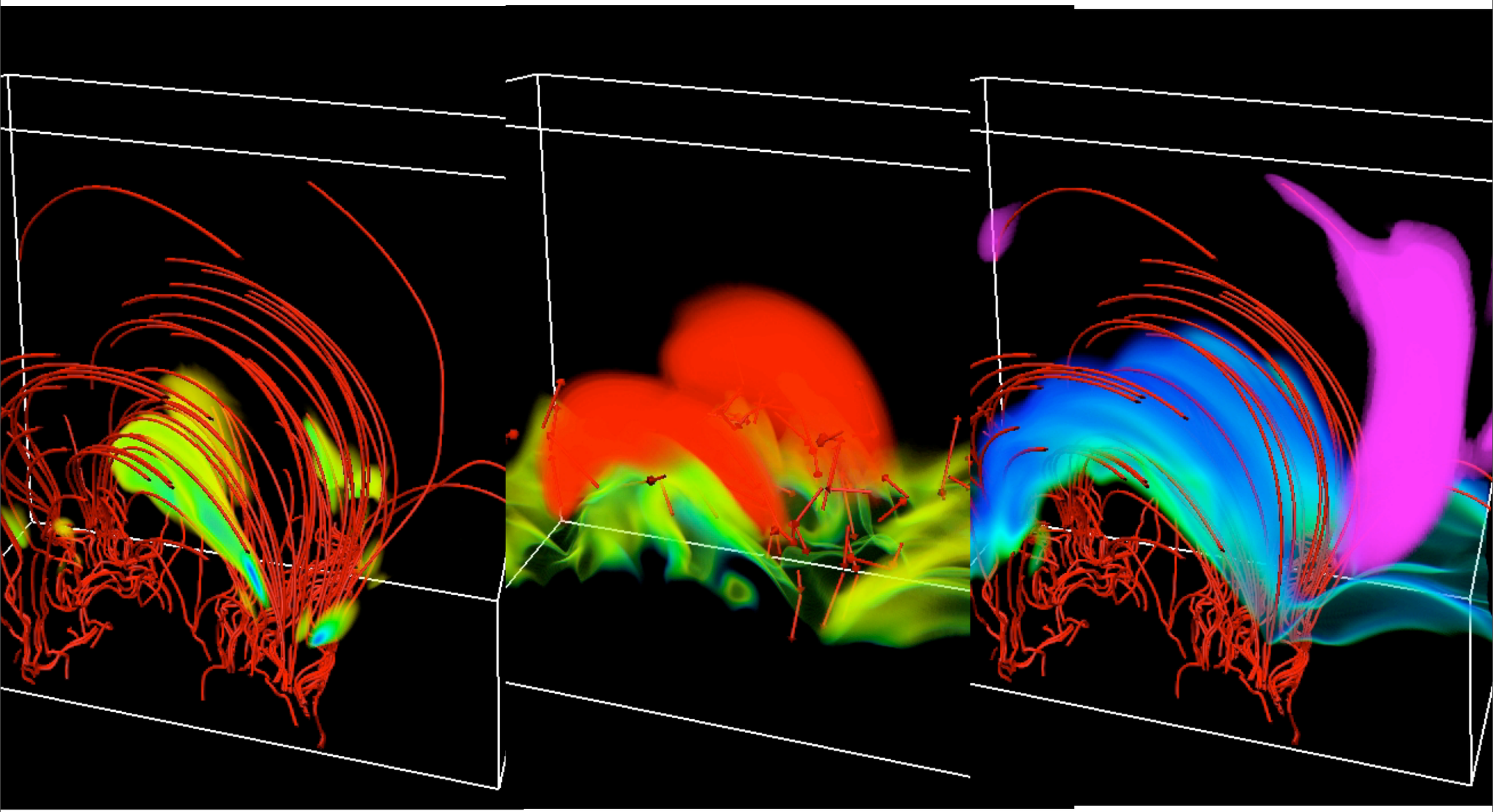


Tube in the chromosphere

Jouel Heating

Density

Temperature



Conclusions

- In photosphere increase in granular size and deformation, adiabatic cooling, etc, as found earlier by eg Cheung et al. 2007. Collapsed granulation and bright points in boundaries of the rising tube.

- At greater heights we find cool, dim, magnetized bubble that tends to expel chromospheric oscillations. Also greatly increased chromospheric scale height.

- Low density in the upper-Chromosphere followed by filament like structure.

- Reconnection with pre-existing field begins about half an hour after tube crosses photosphere. With banana structure and hot blobs at the foot points of the Loops.

- Other structures observed in the chromosphere: jets, spicules and coronal rain observed in the limb with Synthetic Ca II.